

Sanitized Copy Approved for Release 2011/09/21 : CIA-RDP80-00809A000700010247-5

~~CONFIDENTIAL~~

CONFIDENTIAL

50X1-HUM

Of all the foreign books, Haurwitz's book, published in 1941, was closest to the course which the author has taught since 1938 in the Moscow Hydrometeorological Institute and differs from the rest in its orderly composition and clear presentation. However, this book also has two major defects, i.e., it was written for readers completely unacquainted with meteorology and therefore too much elementary material is included; and, more important, the book ignores the results obtained by Soviet authors. Frequently, a superficial solution of a given problem obtained by German or English authors is cited, while a much more complete solution of the same problem obtained by Soviet authors is completely ignored. This defect is also found in all other foreign books (e.g., J. Holmboe, G. E. Forsythe, and W. Gustin's Dynamic Meteorology, published in 1946).

In drawing up his course, the author was confronted with the following tasks:

1. To give a complete presentation of the tasks and capabilities of contemporary dynamic meteorology, particularly the task of forecasting weather, the main practical problem of dynamic meteorology. To draw up on the strictest possible basis a closed system of weather equations, and to analyze these equations, and to analyze these equations and show their degree of applicability to weather forecasting.
2. To state, as completely as possible, the theory of elementary meteorological processes which will serve as a basis for subsequent courses in synoptic meteorology.
3. To investigate some important practical applications, particularly forecasting applications, resulting from the theory of elementary meteorological processes.

The book is divided into 21 chapters. Although, comparatively elementary problems are discussed in some chapters, these chapters are quite necessary for clear understanding of the more complex material presented, as well as of the practical conclusions which are widely used by meteorologists in operational and scientific research.

Even a superficial knowledge of this book will convince the student of the enormous contribution to dynamic meteorology made by Soviet scientists and particularly by the Soviet school of theoretical meteorologists founded by A. A. Fridman. Fridman's scientific interests were exceptionally wide in scope, but he left the deepest imprint in meteorology by creating the Soviet school of theoretical meteorologists, the distinguishing feature of this school being its application of all the modern accomplishments of hydromechanics and thermodynamics to advance meteorology.

Only the more important of the Soviet works which were used in this book are listed. Chapter VIII contains Ye. S. Kuznetsov's detailed and strict derivation of a closed system of equations of hydromechanics, thermodynamics, and the theory of radiation. At the end of the same chapter, the student is introduced to the highly promising ideas of Fridman and Keller in the study of turbulence. These ideas found expression in the so-called Fridman-Keller equations.

Chapter IX presents two important results obtained by Soviet scientists which permitted simplification of the highly complex equations of motion. It also gives the detailed tables drawn up by Fridman (jointly with Hesselberg) characterizing the order of values of meteorological elements and their derivatives, as well as the results obtained by Academician N. Ye. Kochin, who applied the methods of the boundary layer to atmospheric movements.

CONFIDENTIAL

~~CONFIDENTIAL~~
CONFIDENTIAL

50X1-HUM

Chapter XV gives an interesting and important result relating to the special structure of turbulence. This result is known in literature as the "Two-Thirds Law" of Kolmogorov and Obukhov.

Practically all of Chapter XVI, on the variation of wind with height in a turbulent atmosphere, was based on Soviet studies. Likewise, a substantial part of Chapter XVIII on the general circulation of the atmosphere was based on Soviet works. Specifically, this chapter includes the work of Academician V. V. Shuleykin, who clarified the role of continents and oceans in the general circulation mechanism; the mathematical theory of general circulation developed by Kochin; and Ye. N. Blinova's hydrodynamic theory of pressure waves and centers of action of the atmosphere.

The problem of small oscillations of a surface of separation and loss of its stability which was studied by Kochin is investigated in detail in Chapter XIX.

Chapters XX and XXI are given entirely to the results recently obtained by Soviet scientists in integrating weather equations. These results are especially interesting and promising in that they relate to weather forecasting.

Many years of experiments have shown that the main difficulty encountered by the student is in relating the mathematical tool used with the physical essence of phenomena. The author has, therefore, constantly tried to focus the student's attention on the physical side of the phenomena. In some paragraphs, the author was forced to retain in the presentation of works of Soviet researchers a complex mathematical method, which is not included in the mathematics course of higher hydrometeorological schools, without giving a detailed explanation of the method. However, this was unavoidable, since the results had to be included and prolonged excursions into the field of higher mathematics would have burdened the book with superfluous material. The student who is interested in these particular problems can always find the method in a mathematics text.

The terminology used in the book deserves special mention. Often, a term will have one meaning in hydrodynamics and another in meteorology, e.g., gradient, convection, circulation, etc. However, the author did not consider it feasible to introduce new terms in these cases; the words are used for the most part in their meteorological meaning, on the assumption that the readers will be primarily meteorologists rather than specialists in hydrodynamics.

A list of the basic literature used in the compilation of this text and recommended to the student for more thorough study of the problem is appended.

The author would like to thank his teachers, Academician V. V. Shuleykin, I. A. Kibel', Corresponding Member Academy of Sciences USSR; and Professor Ye. S. Kuznetsov; his colleagues at the institute, Professors S. P. Khromov and A. Kh. Khrgian; and also his students L. Matveyev, S. Titov, P. Smirnov, and I. Slavin, who read the manuscript and gave many valuable suggestions for improving it. Special thanks are extended to Sh. N. Gofsteyn for his assistance in the writing of the book.

CONFIDENTIAL

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~~~CONFIDENTIAL~~

50X1-HUM

~~TABLE OF CONTENTS~~

	<u>Page</u>
	9
Foreword	13
I. Introduction	13
1. The Object and Tasks of Dynamic Meteorology	17
2. Systems of Units Used in Meteorology, Dimensional Analysis	20
3. Size and Shape of the Earth	21
4. Distribution of Gravitational Force at the Earth's Surface and in the Atmosphere	24
5. Composition of Atmospheric Air	25
6. Height of the Atmosphere	28
II. Thermodynamics of Ideal Gases	28
1. Thermodynamics of the Atmosphere and Physical Thermodynamics	28
2. First and Second Laws of Thermodynamics	29
3. Parameters of State of a Thermodynamic System	30
4. Mass, Volume, Density	31
5. Pressure	34
6. Temperature	35
7. Equations of State	38
8. Mixing of Ideal Gases	39
9. Equations of Change of State of a Gas	41
10. Quantity of Heat. Specific Heat	43
11. Equation Describing First Law of Thermodynamics	44
12. Internal Energy of an Ideal Gas	45
13. Dependence of Work of Expansion Upon Thermodynamic Path (Mean Free Path). Indicator $p-v$ Diagram	47
14. Various Forms of Equation of Heat Flow for an Ideal Gas	49
15. Polytropic Processes	54
16. Dry Adiabatic Process. Potential Temperature	56
17. General Theory of Thermodynamic Diagrams	63
18. Mathematical Expression of Second Law	69
III. Thermodynamics of Water Phases	69
1. Water Phases and Their Equilibrium	71
2. Water Vapor	74
3. Specific Heat of Water Vapor	75
4. Thermal Conditions of (Liquid) Water and Ice	75
5. Basic Equations of Thermodynamics	77
6. Latent Heat of Evaporation	80
7. Basic Relationships Characterizing Change of Phases	83
8. Supercooled Water and Supersaturation Relative to Ice	84
9. Vapor Pressure Over a Curved Surface	86
10. The Role of Condensation Nuclei	88
11. Entropy of Water	89
12. Thermodynamic Surface of State of Water	91
IV. Thermodynamics of Moist Air	91
1. Parameters of State of Moist Air	93
2. Moisture Characteristics	96
3. Graphical Determination of Moisture Characteristics	100
4. Equation of State of Moist Air	102
5. Specific Heats of Moist Air	102

- 4 -

~~CONFIDENTIAL~~~~CONFIDENTIAL~~

CONFIDENTIALCONFIDENTIAL

50X1-HUM

	Page
6. Adiabatic Processes in Moist Air	103
7. Dry Stage. Nonsaturated Moist Air	104
8. Rain Stage	105
9. Hail Stage	107
10. Snow Stage	109
11. Pseudoadiabatic Process	110
12. Dry and Moist Adiabats in Aerological Diagrams	112
13. Isenthalpic Processes. Mixing of Two Moist Air Masses	113
14. Isenthalpic Evaporation of a Water Drop. Equivalent Temperature	115
15. Wet-Bulb Temperature	118
16. Pseudowet-Bulb Temperature	120
17. Thermohygroscopic Characteristics of Air Masses	122
18. Equivalent-Potential Temperature	123
19. Potential-Equivalent Temperature	124
20. Pseudopotential Temperature	125
21. Pseudoequivalent Temperature	128
22. Pseudopotential Temperature of a Wet-Bulb Thermometer	128
23. Comparison of Thermohygroscopic Characteristics	129
 V. Statics of the Atmosphere	 133
1. Basic Problem of Statics of the Atmosphere	133
2. Mathematical Determination of Parameters of State at a Given Geometric Point	134
3. Scalar Field	135
4. Vector Field	138
5. Field of the Earth's Attraction	142
6. Pressure	143
7. Equation for Absolute Motion of a Particle at Rest With Respect to the Earth's Surface	144
8. Field of Gravitational Force	146
9. Pressure Field and Gravitational Field	150
10. Barometric Formula for a Polytopic Atmosphere	152
11. Homogeneous, Adiabatic, and Isothermal Atmosphere	155
12. Barometric Mean Temperature	156
13. Determination of Absolute and Relative Geopotential of an Isobaric Surface	159
14. Analytic Calculation of Geopotential of an Isobaric Surface	161
15. Graphical Representation and Calculation of Dynamic Height	162
16. Relationship Between Height of Tropopause and Temperature of the Lower Troposphere	166
17. Laplace Barometric Formula	170
18. Standard Atmosphere	170
 VI. Stability of Static Equilibrium	 172
1. Quasi-static Condition of Motion	173
2. Dry-Adiabatic Temperature Changes of an Ascending Particle	176
3. Change of Moisture Characteristics With Height in Adiabatic Rise of Moist Air Not Saturated With Water Vapor	180
4. Moist-Adiabatic Gradient	186
5. Equilibrium Conditions for an Atmosphere of Dry Air	189
6. Speeding Up of Convection. Energy of Instability	193
7. Potential Temperature as a Stability Criterion for Dry Air	196
8. Influence of Vertical Movements on Stability of Dry Air	198
9. Polytopic Change of Temperature With Height	198

CONFIDENTIAL

CONFIDENTIALCONFIDENTIAL

50X1-HUM

	<u>Page</u>
10. Stability Criteria for Unsaturated Moist Air	200
11. Stability and Instability	202
12. Method of Parcels	208
VII. Radiation	213
1. Basic Laws of Radiation	213
2. Solar Radiation	218
3. Absorption of Long-Wave Radiation in the Atmosphere	223
4. Heat Balance of the Earth	226
VIII. Equations of Hydromechanics and Thermodynamics, and Theory of Radiation	229
1. Lagrange and Euler Methods	229
2. Individual, Local, and Convective Derivatives	231
3. Deformation of a Particle of Air	233
4. Continuity Equation	237
5. Viscosity or Internal Friction	239
6. Equations of Motion of a Viscous Fluid	243
7. System of Equations for an Incompressible Viscous Fluid	244
8. Equation of Heat Flow	247
9. Flow of Heat Provided by Transformation of Radiant Energy Into Thermal Energy	254
10. Equation of Transfer of Radiant Energy	259
11. Complete System of Equations of Hydromechanics, Thermodynamics, and Theory of Radiation. Calculation of Moisture	263
12. Various Forms of Motion of a Fluid	266
13. Equations of Averaged Motion of a Fluid	269
14. Transformation of Kinetic Energy of Average Motion Into Kinetic Energy of Pulsations	274
15. Fridman-Keller Equations	278
IX. Equations of Motion of the Atmosphere and Their Simplification	283
1. Equations of Motion of the Atmosphere as an Ideal Fluid	283
2. Equations of Motion of a Turbulent Atmosphere	287
3. Helmholtz Similarity Principle	289
4. Dynamic Similarity. Reynolds Number	292
5. Laminar Boundary Layer	295
6. A Boundary Layer in a Temperature Field and in a Pressure Field	302
7. Turbulent Boundary Layer	303
8. Order of Values of Meteorological Elements	306
9. Boundary Layers in the Atmosphere	313
X. Simplest Movements of the Atmosphere Without Friction	319
1. Zonal Current	319
2. Equations of Motion of the Atmosphere as an Ideal Fluid in Natural and Standard Coordinates	324
3. Geostrophic Wind	330
4. Slope of Isobaric Surfaces. Geostrophic Wind on Charts of Baric Topography	337
5. Inertial Motion of Air	340
6. Cyclostrophic Wind	342
7. An Arbitrary Horizontal Current	343
8. Trajectories, Current Lines, and Isobars	351
9. Ageostrophic Movements	356

CONFIDENTIAL**CONFIDENTIAL**

~~CONFIDENTIAL~~CONFIDENTIAL

50X1-HUM

	<u>Page</u>
XI. Variation of Geostrophic Wind With Height	360
1. Basic Equations	360
2. Thermal Wind and Thermal Gradient	364
3. Variation of Geostrophic Wind With Height as a Function of Position of Pressure and Thermal Gradients	367
4. Variation of Temperature and Pressure With Time as Functions of Change in Direction of Geostrophic Wind With Height	372
5. Variation of Wind With Height in Occluded Cyclones and Anti-cyclones	374
XII. Mechanism of Pressure Change	379
1. Relationship Between Temperature Variation of an Air Column and Pressure Change	379
2. Effect of Advection of Air to Great Heights on Pressure Change at the Earth's Surface	382
3. Tendency Equation	386
XIII. Surfaces of Separation	394
1. Discontinuity Surfaces. Discontinuities of Zero and First Orders	394
2. Dynamic and Kinematic Conditions	396
3. Slope of a Surface of Separation	400
4. A Surface of Separation in a Pressure Field	403
5. A Surface of Separation in a Geostrophic Wind Field	408
6. Variation of Gradient Wind With Height in Region of a Front	409
7. Position of a Surface of Separation in a Nonstationary Wind Field	411
8. Classification of Fronts	414
9. Frontogenesis and Frontolysis	418
XIV. Kinematics of Pressure Field	424
1. Characteristic Curves and Special Points in a Pressure Field	424
2. Motion of Lines	426
3. Velocity and Acceleration of Isobars	430
4. Velocity and Acceleration of Troughs and Ridges	438
5. Displacement of Pressure Centers. Other Formulas for Extrapolation of Pressure Field	441
XV. Turbulent Exchange. Spectral Structure of Turbulence	445
1. Basic Formulas of Turbulent Exchange	445
2. Transfer of a Quantity of Motion	452
3. Transfer of Eddies	457
4. Transfer of Other Air Properties	460
5. Effect of Thermal Stratification on Development of Turbulence. Richardson Number	462
6. Roughness	465
7. Horizontal Turbulent Exchange of Masses	467
8. Spectral Structure of Turbulence	470
9. Kolmogorov and Obukhov's "Two-Thirds Law"	472

CONFIDENTIAL~~CONFIDENTIAL~~

50X1-HUM

CONFIDENTIAL

	<u>Page</u>
XVI. Variation of Wind With Height in a Turbulent Atmosphere	475
1. Variation of Wind Velocity and Coefficient of Exchange in Surface-Air Layer	475
2. Distribution of Coefficient of Exchange in a Boundary Layer	481
3. Variation of Wind With Height and Turbulent Exchange in a Planetary Boundary Layer	487
4. Variation of Wind With Height for a Variable Coefficient of Exchange	494
5. Diurnal Behavior of Wind Velocity	500
XVII. Energy of Atmospheric Motion	504
1. Energy Transformation in the Atmosphere	504
2. Energy Balance Equation of an Individual Air Particle	505
3. Energy Balance Equation of an Arbitrary Air Mass	507
4. Energy of a Vertical Column of Air	511
5. Energy Liberated in Vertical Redistribution of Masses	512
6. Transformation of Kinetic Energy of Averaged Motion of the Atmosphere Into Kinetic Energy of Turbulence	517
7. Energy Balance Equation of Turbulence of the Atmosphere	519
XVIII. General Circulation of the Atmosphere	522
1. General Considerations	522
2. Survey of General Circulation of the Atmosphere	523
3. Geographical Distribution of Solar and Outgoing Radiation	532
4. Theorems on Circulation	536
5. Application of Circulation Theorems to General Circulation of the Atmosphere	544
6. Heat Transfer From the Equator to the Pole	546
7. Heat Transfer From Oceans to Continents	547
8. N. Ye. Kochin's Mathematical Theory of General Circulation	550
9. Ye. N. Blinova's Hydrodynamic Theory of Pressure Waves and Centers of Action of the Atmosphere	553
XIX. Theory of Perturbations of Atmospheric Motion	558
1. Application of Theory of Small Oscillations to Movements of the Atmosphere	558
2. Differential Equations of Small Perturbations	559
3. Wave Motion in the Atmosphere	563
4. Gravitational Waves on Free Surface of an Incompressible Fluid	564
5. Two-Dimensional Waves on a Surface of Separation of Two Currents	571
6. Small Oscillations of Surfaces of Separation	578
7. Zonal Oscillations of a Surface of Separation	582
8. Stability of a Surface of Separation With Respect to Non-Zonal Oscillations	591
XX. Theoretical Method of I. A. Kibel' for Weather Forecasting	601
1. Boundary Layers and the Free Atmosphere	601
2. Determination of u and v From Equations of Motion	603
3. Determination of w from Continuity Equation	605
4. Summary of Formulas for Determining u, v, w in First and Second Approximations	606
5. Evaluation of Dependency of Temperature on Height	607

CONFIDENTIAL

CONFIDENTIAL

~~CONFIDENTIAL~~CONFIDENTIAL

50X1-HUM

	<u>Page</u>
6. First Basic Relationship of I. A. Kibel'	609
7. Boundary Condition for Tropopause	612
8. Solution of Problem by a Simplified Method	615
9. Graphical Method of Forecasting in First Approximation	617
10. Isotherms and Leading Current	619
11. Dynamic Pressure Change	622
12. Relationship Between Dynamic Pressure Changes and the Geometrical Properties of Fields θ and T_0	624
XXI. Integration of Weather Equations	632
1. System of Weather Equations	632
2. Distribution of Temperature in the Earth's Atmosphere Provided by Radiant and Turbulent Heat Exchange	637
3. Average Yearly Distribution of Temperature in the Earth's Atmosphere	644
4. Diurnal Behavior of Temperature in a Mixing Layer According to Dorodnitsyn	655
5. Theoretical Method of Predetermining Diurnal Behavior of Temperature	664
6. Transformation of an Air Mass Under Influence of Underlying Surface	679
Appendices	685
Bibliography	702

- E N D -

- 9 -

CONFIDENTIAL~~CONFIDENTIAL~~